Development of a 233 GHz High-Gain Traveling Wave Amplifier

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Abstract: *We present development plans for a 233 GHz, serpentine waveguide vacuum electron amplifier employing an embedded monofilament microfabrication technique based on UV-LIGA. Output power from the circuit is predicted to exceed 140 W in conjunction with a newly developed electron gun at 20 kV and 124 mA. Design, fabrication and integration progress will be discussed.*

Keywords: Electron tubes; Lithography; Millimeter wave tubes; Millimeter wave amplifiers; Traveling wave tubes.

Introduction

With use of an embedded polymer monofilament technique [1] invented at the U.S. Naval Research Laboratory for use with ultraviolet photolithography and electroforming (UV-LIGA), all-copper slow wave circuits can be microfabricated that simultaneously include arbitrarily-sized, geometrically round beam tunnels. These techniques are being utilized at W-band (95 GHz), G-band (220 GHz, 233 GHz), and 670 GHz to date. The recent successful demonstration of the 63 W NRL G-band serpentine waveguide amplifier [2, 3] was the first demonstrated amplifier to use a UV-LIGA fabricated circuit. The small-signal gain was limited to about 15 dB due to restricted magnetic interaction length of the available components. This new high-gain amplifier will be fabricated using the same techniques for 231.5 GHz to 235 GHz, an FCC Radiolocation band.

Amplifier Design

The compound, hybrid serpentine waveguide (SWG) amplifier [4] is designed to operate from a single, round 20 kV electron beam (Table 1). Using different waveguide narrow-wall dimensions in the bends than in the gaps, and a jump in the period, a small signal gain of over 30 dB is predicted to be stable in a single section and capable of over 90 W output power with 113 mW input, saturating at 140 W. The bandwidth is predicted to encompass the frequency range of interest, 231.5 GHz to 235 GHz. Simulations using the newly developed GPU PIC code NEPTUNE predict stable performance with -25 dB reflection on the input and output.

Circuit Fabrication

The circuit is being fabricated using a two-layer UV-LIGA method (Fig. 1), where the first layer thickness is such that it contains only the serpentine circuit pattern without the beam tunnel, while the second layer contains both the entire beam tunnel as well as the remaining serpentine pattern. Rather than the using a photolithographic mask, a laser pattern generator (Heidelberg μPG101) is expected to be used for tighter tolerance control in the planar dimensions.

Table 1. Target Operating Parameters

Parameter	Target Value
Frequency Range (GHz)	231.5-235
Beam Voltage (kV)	20
Beam Current (mA)	124
Small Signal Gain (dB)	30.6
-1 dB Bandwidth (GHz)	4
Max output power (W)	140
Number of gaps	62 + 31

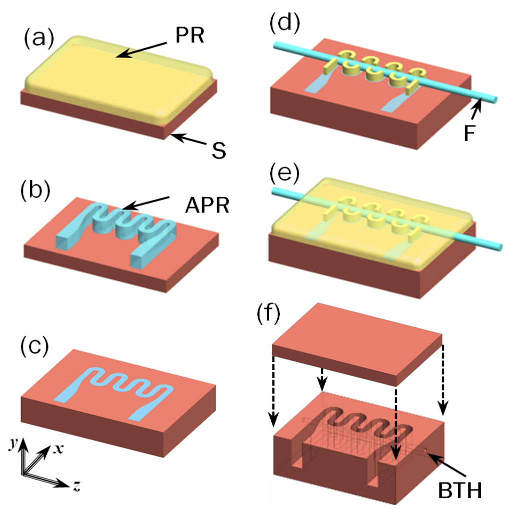

Figure 1. The two-layer UV-LIGA microfabrication process: (a) SU-8 photoresist (PR) is applied to a copper substrate. (b) Activated SU-8 mold after UV patterning. (c) After electroforming first layer of copper. (d) SU-8 filament alignment posts patterned to guide polymer monofilament F to hold the size, shape and location of the electron beam tunnel. (e) Embed filament and posts in SU-8 and repeat steps (b)-(c). (f) Remove SU-8 and filament, braze flat lid on. APR: activated photoresist, BTH: beam tunnel hole.

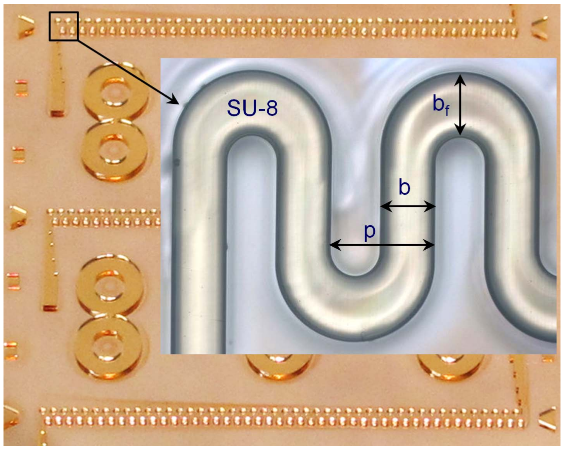

Figure 2. Initial SU-8 patterning on copper of the hybrid serpentine waveguide structure using a laser pattern generator.

The tolerances needed vary widely depending on the feature. The least sensitive structure is the waveguide narrow-wall width and will need to remain within ±10 µm. The waveguide broad wall (total depth of the electroformed copper) must remain within ±2 µm. The beam tunnel hole must be aligned within ±5 µm in the ***x***-direction, the plane of the serpentine bends. If there is a significant offset or tilt in the beam tunnel in this plane, the gap-to-gap phase is no longer consistent, leading to extraneous stop bands that could cause oscillation. The beam tunnel must be within about ±20 µm in the ***y***-direction, or there could be a reduction in gain.

The beam tunnel alignment relies on the accuracy of the alignment of the UV-transparent polymer filament [1]. To meet the requirements, filament alignment is performed using an extra layer of SU-8 containing alignment pegs to hold the filament in place. These pegs are engulfed by the next SU-8 layer and are removed with the bulk of the SU-8 during the removal process.

Gun and Windows

Figure 3 shows the gun design in the MICHELLE gun code with an effective diameter of 170 µm over the 2.2 cm long interaction region. The total device size is 14 cm dia. x 11 cm high, with weight of just over 7 kg. The gun contains an additional focus electrode that is useful for adjusting the beam current without interception. A tolerance study has been completed and the design is robust to expected alignment tolerances. The input window will be the same construction as the 220 GHz TWT program [5]: A pill-box resonant window covering 218 to 248 GHz at below -30 dB S_{11} is predicted.

Input and output couplers will be integrated as much as possible on the wafer substrate to minimize the number of external brazing steps. An overmoded output waveguide is being studied to reduce output losses. Likewise, the output window may be oversized to reduce the electric field stress and the reliance on tight tolerances.

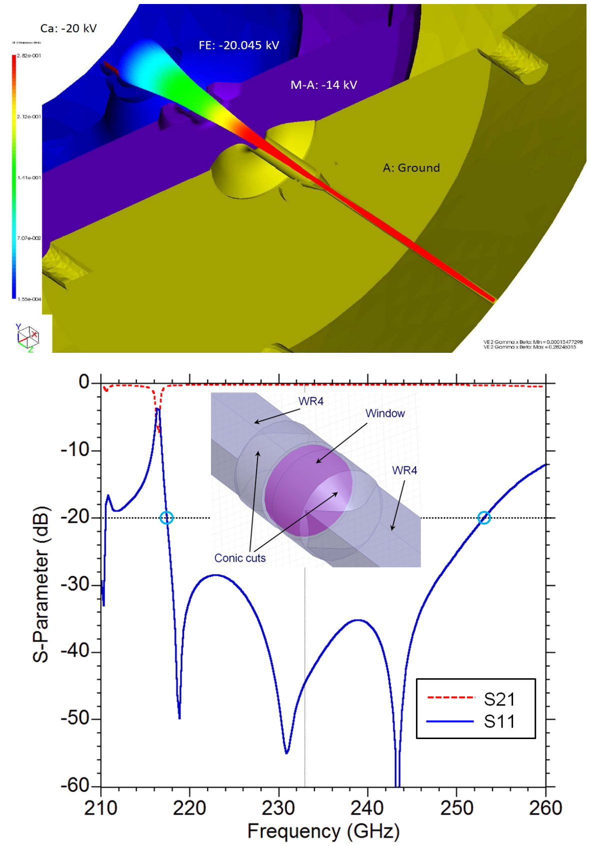

Figure 3. (top) Gun design in MICHELLE. (bottom) Simulation of pillbox resonant window structure for the input predicting over 30 GHz BW at -20 dB S_{11}.

Acknowledgement

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